CHAPTER C.9
HABITAT SWITCHING MODULE

Jenneke M. Visser[1] (Co-Chair)
Gregory D. Steyer[2] (Co-Chair)
Gary P. Shaffer[3]
Susanne S. Höppner[4]
Mark W. Hester[5]
Enrique Reyes[5]
Paul Keddy[3]
Irving A. Mendelssohn[1]
Charles E. Sasser[1]
Christopher Swarzenski[6]

[1]   *Coastal Ecology Institute, Louisiana State University, Baton Rouge, LA 70803*
[2]   *U.S. Geological Survey, National Wetlands Research Center, Baton Rouge, LA 70894*
[3]   *Department of Biological Sciences, Southeastern Louisiana University, Hammond, LA 70506*
[4]   *Department of Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge, LA 70803*
[5]   *Pontchartrain Institute for Environmental Sciences, University of New Orleans, New Orleans, LA 70148*
[6]   *U.S. Geological Survey, Water Resources Division, Baton Rouge, LA 70816*

9.1   INTRODUCTION

The Louisiana coast supports a wide variety of habitats/vegetation (Penfound and Hathaway 1938; O'Neil 1949; Chabreck 1972; Wharton *et.al.* 1982; Sasser *et.al.* 1994, Visser *et.al.* 1998 and 2000). Those included in this habitat switching module are swamp forest, fresh marsh, intermediate marsh, brackish marsh, saline wetlands, open water, and upland habitats (Figure C.9-1). These selections reflect the available information regarding the distributions of these habitats, but does not diminish the importance of habitats that were not included in the module such as bottomland hardwoods, mangroves, scrub shrub, submerged aquatics, barrier islands, *etc*. It is recognized that increasing temperatures, which are expected due to global climate change along the Gulf coast (Twilley *et.al.* 2001) may increase the extent of mangrove forest at the expense of saline marsh.

9.2   RATIONALE OF ASSUMPTIONS AND INTERACTIONS

9.2.1   Habitat Switching Component

It is generally accepted that salinity and inundation are the major driving forces in the distribution of coastal wetland habitats (Mitsch and Gosselink 2000), although these are modified by other factors including fertility, herbivory, disturbance, and burial (Keddy 2001). Many edaphic factors have been shown to be highly correlated with the

observed driving forces in estuaries (Palmisano 1970; Ross *et.al.* 2000). The importance of fire and grazing as additional factors is acknowledged (*e.g.*, Grace and Ford 1996; Evers *et.al.* 1998); however, these will probably not be impacted by the subprovince frameworks and therefore are not included in this module. Figure C.9-1 shows the potential pathways of change among habitats and the driving force(s) associated with each change. It is important to note that the intensity threshold of these forcing functions can differ depending on the direction of the state change from one habitat to the next and that these thresholds are based on relatively few data sources. Differing forcing functions depending on direction of state change are explained by the following example: much higher inundation levels are required to convert established vegetation into open water than can be tolerated by vegetation establishing on created mudflats.

The habitat switching assumptions made are (1) that emergent herbaceous communities appear to switch in progression from one community to another along a salinity gradient (*i.e.*, fresh< >intermediate< >brackish< >saline; (2) swamp forests can switch to intermediate marsh based on salinity These switches assume that seed sources for these habitats are available. It is also assumed that upland habitats will remain upland habitats. It is also understood that the responses of vegetation to physical factors are often indirect, and switching is mediated by factors including competition, grazing, fertility and even mutualism (Grace and Wetzel 1981; Bertness and Yeh 1994, Grace and Ford 1996; Keddy 2001).
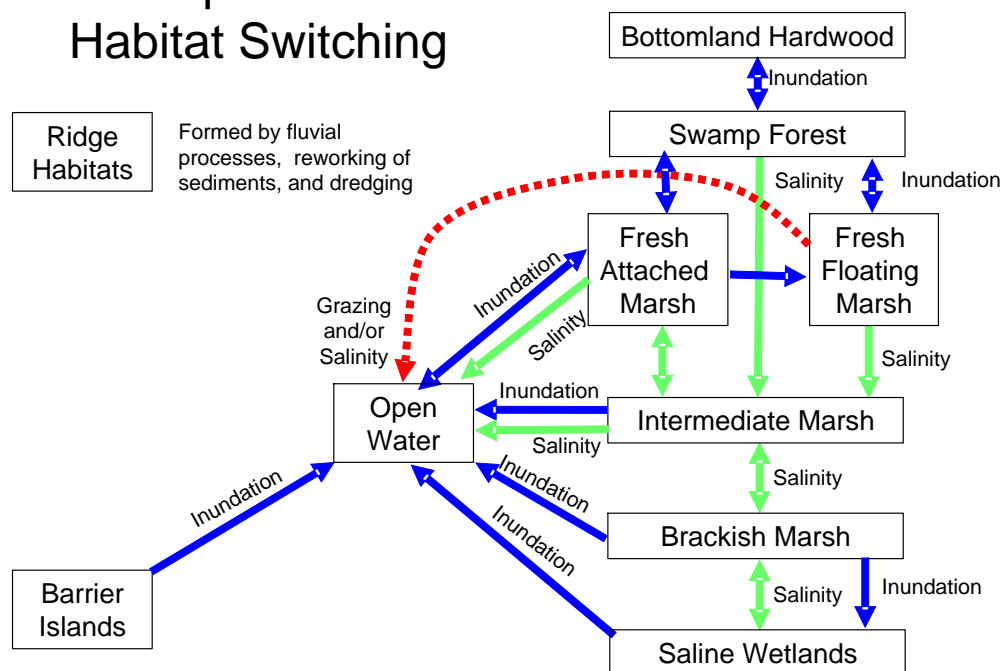
Figure C.9-1 Conceptual Model for the Habitat Switching Component. Solid arrows represent switching driven by average annual salinity. Stippled arrows represent switching driven by inundation.
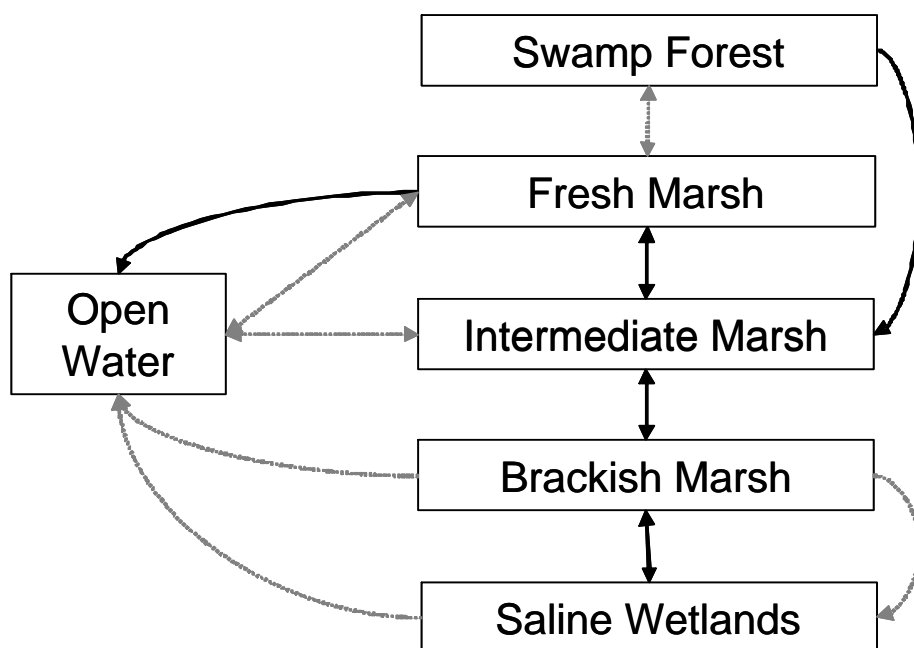

Figure C.9-2 Simplified Model for the Habitat Switching Component

Table C.9-1 lists the salinity and inundation levels observed in the different habitat types. These values will serve as a guide for thresholds in the habitat switching module. The threshold differs based on the direction of change. For example, Fresh Attached Marsh changes to Intermediate Marsh if the average annual salinity exceeds 2.5 ppt, while Intermediate Marsh changes to Fresh Attached Marsh if the average annual salinity drops below 1 ppt.

Table C.9-1   Restrictions in Salinity and Inundation for the Major Habitat Types[1]

Habitat	Salinity (yearly average)	Source for Salinity Restrictions	Inundation (% of year)	Source for Inundation Restrictions
Bottomland Hardwood	< 2 ppt	Conner *et.al.* (1997)	< 30%	Conner *et.al.* (1997)
Swamp Forest	< 4 ppt	Höppner (2002)	Up to whole year if not stagnant	Höppner (2002)
Fresh Floating Marsh	< 2 ppt	Chabreck (1970), Hester *et.al.* (2002)	Not Applicable	
Fresh Attached Marsh	< 2 ppt	Chabreck (1970)	Up to whole year if not stagnant and below 30 cm of water on marsh	Evers *et.al.* (1998)
Intermediate Marsh	2-6 ppt	Chabreck (1970)	Up to whole year if not stagnant and below 30 cm of water on marsh	Evers *et.al.* (1998)
Brackish Marsh	6-15 ppt	Chabreck (1970)	< 64%A	Sasser (1977)
Saline Wetlands	> 15 ppt	Chabreck (1970)	< 80%A	Sasser (1977)

[1]*Restrictions are estimated on limited data and the authors' experience. These restrictions are subject to change if additional data becomes available*

Salinity predominantly drives the change among fresh, intermediate, brackish and saline habitats. Extreme salinities may lead to conversion of fresh and intermediate marshes to open water (Flynn *et.al.* 1995). The salinity stress on a habitat may be worsened with inundation stress. At higher inundation levels, the salinity tolerance of the vegetation is lower; the converse is also true. This is especially true for *Panicum hemitomon* and *Spartina patens* (Hester *et.al.* 2002). A conceptual diagram of the interaction among salinity and elevation is shown in Figure C.9-3. This diagram demonstrates an overlap in niche space among vegetation community types, which is commonly the case in the natural system. The algorithms developed in this document are limited in that they do not include an interaction between driving forces.
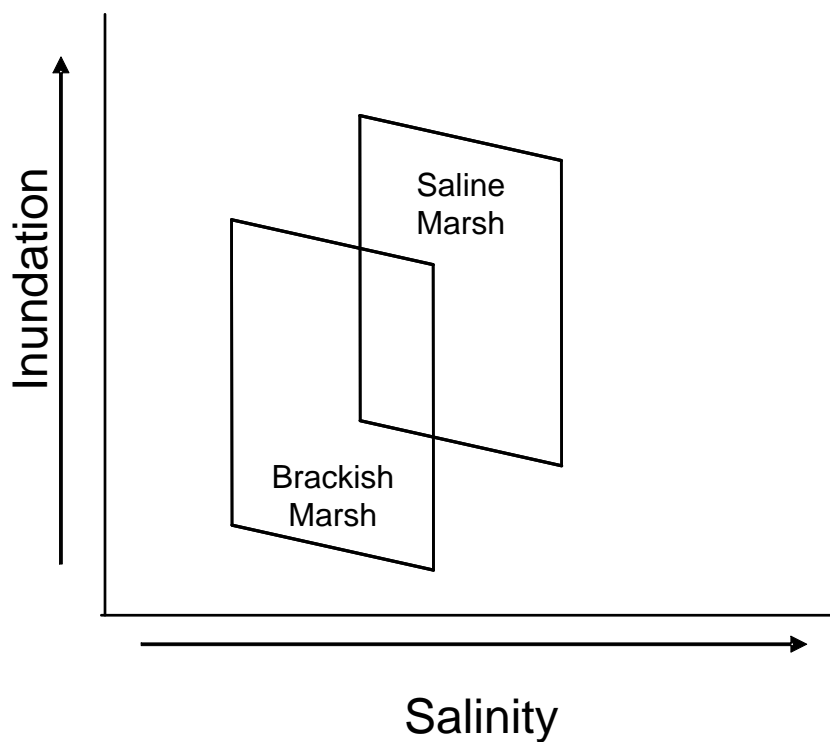
Figure C.9-3 Conceptual Diagram Demonstrating Interaction Between Salinity and Inundation Restrictions of Brackish and Saline Marsh Vegetation

Evidence from vegetation surveys conducted in 2000 and 2001 suggest that herbaceous vegetation types can switch among states over one growing season (Chabreck and Linscombe 2000, 2001). Therefore a one-year time step is used in the habitat-switching component. Inundation that exceeds the restriction of the intermediate, brackish, and saline habitats typically leads to a conversion to open water. Inundation exceeding the restrictions for fresh marsh can lead to floating marsh in areas with organic soils. In fresh marsh areas with mineral soil, the same inundation may lead to a conversion to open water. Vegetation establishment on mudflats occurs when inundation is less than 50 percent of the year (Shaffer *et.al.* 1992). Reliable inundation estimates were not available due to the fact that the current hydrology simulation models are restricted to channel hydrology and the absence of coast wide elevation data of the wetland area. Therefore, the output from the land change module was used to determine the switch between wetland or open water. If a .3 mi^2 (1km^2) cell consisted of greater than 50% water than the cell was switched or remained open water. If the cell switched from water to wetland (*i.e.* less than 50% water), then the habitat was determined based on the average annual salinity for the cell as follows: <2 ppt fresh marsh, 2-6 ppt intermediate marsh, 6-15 ppt brackish marsh, >15 saline marsh.

9.2.2   Habitat Productivity Component

The productivity component evaluates the effect of salinity and inundation on the productivity of the habitat. Productivity algorithms were developed for all herbaceous and forested wetlands based on the published and unpublished data that was readily available. Extensive literature was available on the effect of salinity on the productivity of the dominant species in each habitat (*Taxodium distichum, Panicum hemitomon,*

Sagittaria lancifolia, Spartina patens, and *Spartina alterniflora*). Most of this data was gathered using greenhouse experiments. These studies used various measurements of productivity including total biomass, stem/leaf elongation, photosynthesis etc. These data are represented as maximum productivity estimates on a percentage scale. Most of the data could be classified into three inundation classes: saturated soil, soil flooded with greater than 10 cm of water, or drained soil. At least 80% of the data were collected from experiments using saturated soils. To better illustrate the relationship of salinity and productivity, regardless of inundation, a linear regression was fitted to these data with an artificial forcing through 100% production at a certain level of salinity (see Table C.9-2). The resulting salinity-production relationship's for the different habitats are presented in Figure C.9-4.

Table C.9-2   Salinity Assumed to Have 100% Production and Regression Coefficients for the Different Habitat Types

Habitat Type	100% production	Decrease in productivity per 1 ppt
Swamp Forest (*Taxodium distichum*)	0 ppt	8.4%
Fresh Marsh (*Panicum hemitomon* and *Sagittaria lancifolia*)	0 ppt	11.1%
Intermediate Marsh		6.8%
Sagittaria lancifolia	0-2 ppt	11.4%
Spartina patens	0-2 ppt	2.3%
Brackish Marsh (*Spartina patens* and *Distichlis spicata*)	0-7.5 ppt	2.6%
Saline Marsh (*Spartina alterniflora* and *Juncus roemerianus*)	0-10 ppt	2.1%

Figure C.9-4a Effect of Salinity on Production of Swamp Forests as Derived from a Literature Review

Figure C.9-4b Effect of Salinity on Production of Fresh Marsh with Saturated Soils as Derived from a Literature Review

Figure C.9-4c Effect of Salinity on Production Intermediate *Sagittaria* Marsh as Derived from a Literature Review

Figure C.9.4d   Effect of Salinity on Production of Intermediate *Spartina alterniflora* Marsh as Derived from a Literature Review
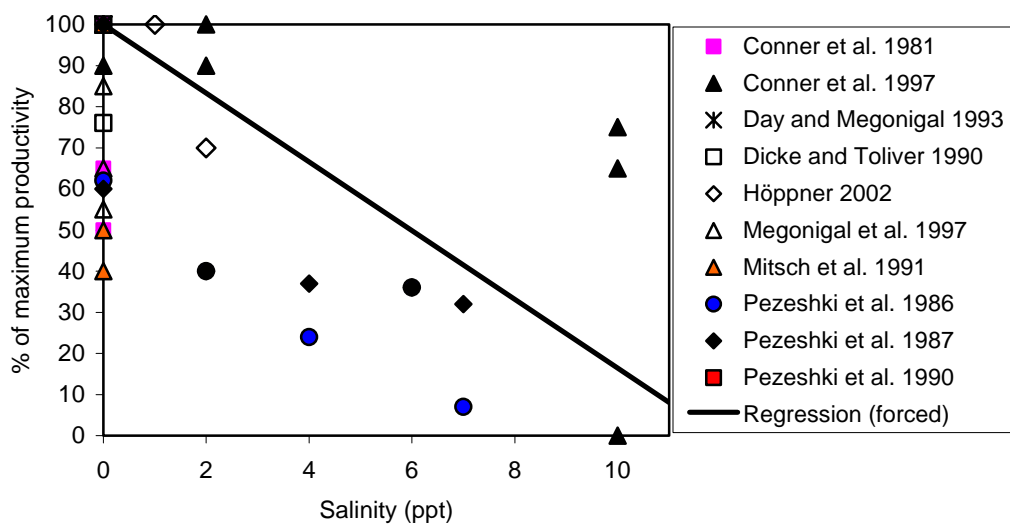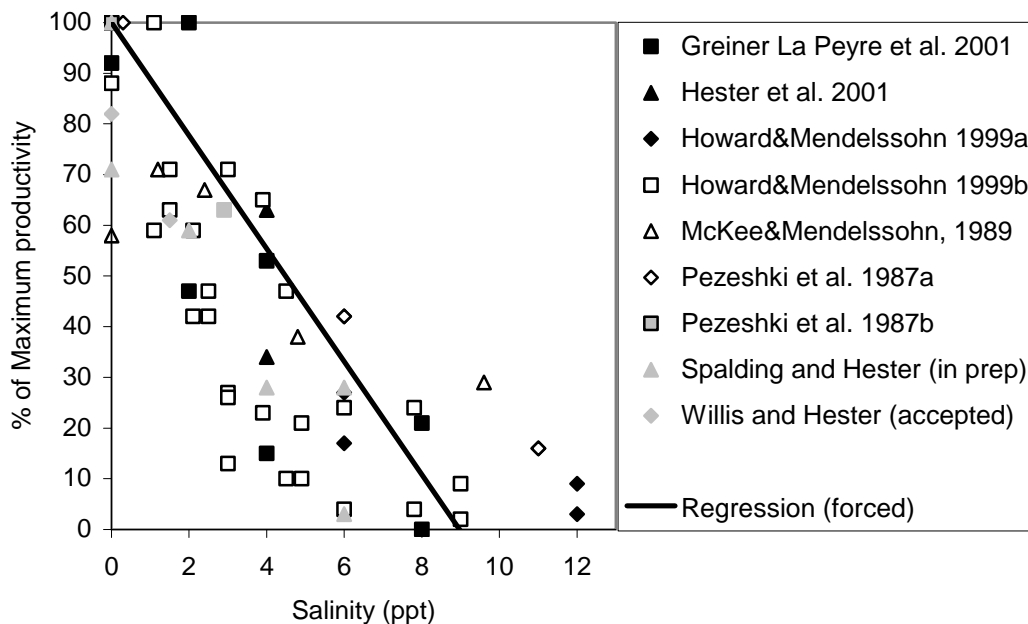
Figure C.9-4e Effect of Salinity on Production of Brackish Marsh as Derived From a Literature Review

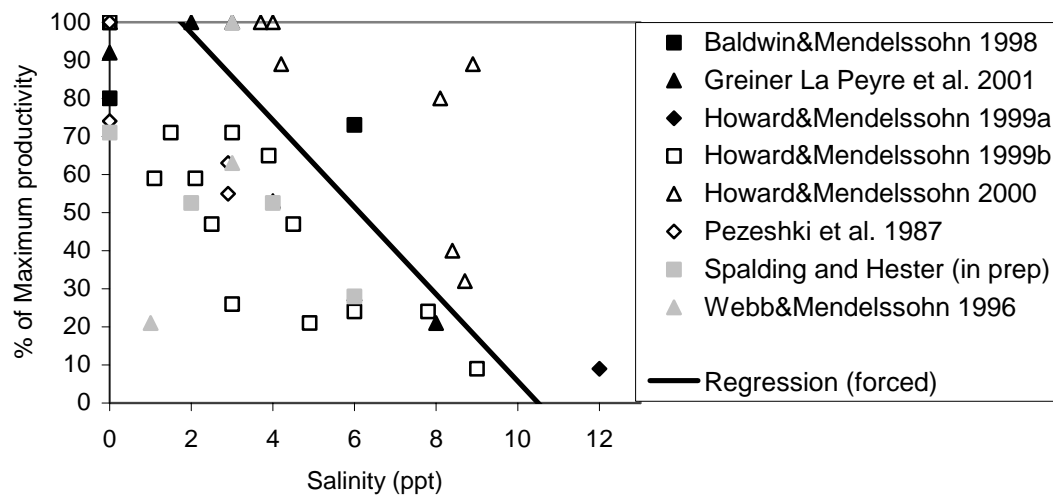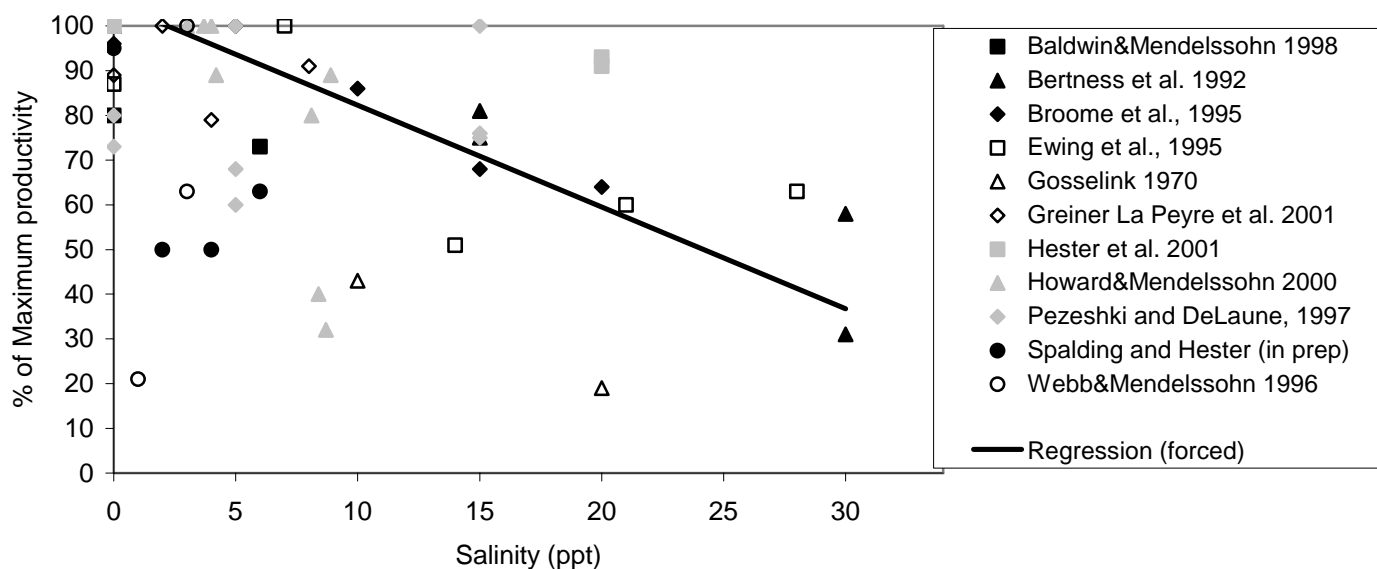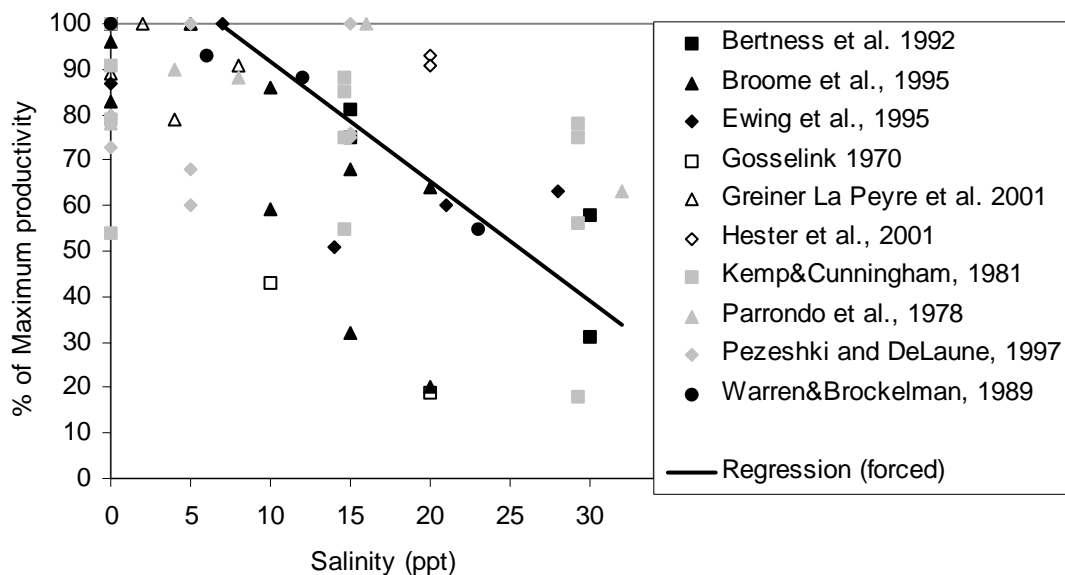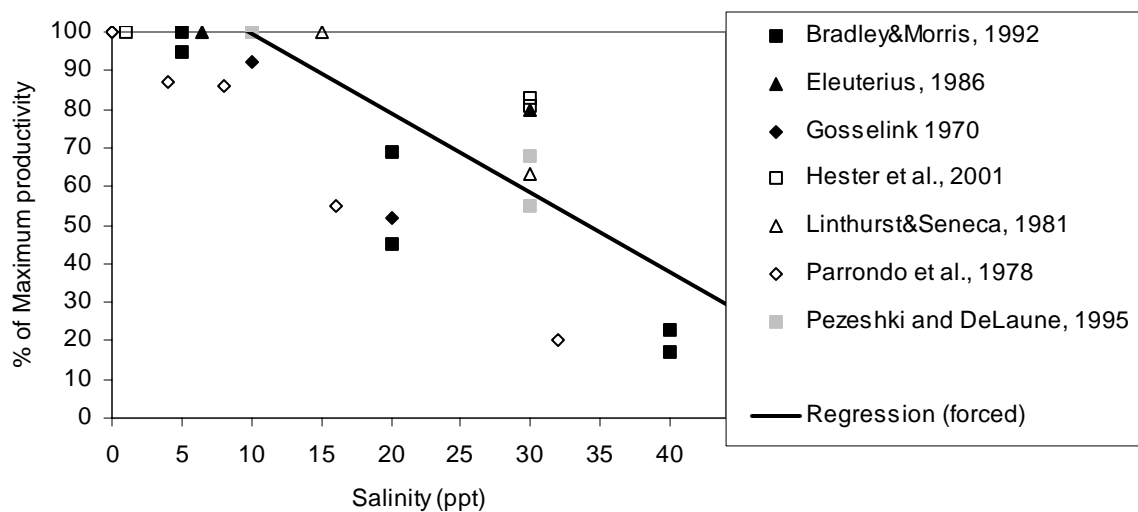**Figure 9.4f   Effect of Salinity on Production of Saline Marsh as Derived from a Literature Review**

Inundation also has a significant effect on production (Conner and Day 1992, Broome *et.al.* 1995, Webb and Mendelssohn 1996, Höppner 2002). However, the exact relationship between inundation and productivity is not yet clearly determined. Best professional judgment based on over 175 years of combined field experience by the authors was used to determine how to scale the influence of inundation. Optimal flooding for fresh, intermediate and saline marshes was assumed to occur at 50% inundation per year, whereas optimal flooding for brackish marsh was assumed to occur at 40%. There is a possibility to get a better substantiation of this by combining the data from sod lowering experiments in the field (*e.g.* Webb and Mendelssohn 1996) with water level data from the same time period and approximate location). It was assumed that the highest production occurs with normal tidal inundation. It was also assumed that production is slightly depressed at very low to no inundation, because this would restrict the delivery of nutrients to the wetlands and would decrease the removal of toxic compounds. Production is reduced to 25% of maximum production at the highest inundation tolerated by the habitat (Megonigal *et.al.* 1997, Höppner 2002, Hester *et.al.* 2002).

The combined influences of salinity and inundation drive the production algorithms. Maximum production values for each habitat type were determined by compiling several variables from the literature needed to calculate production values in a consistent method (Table C.9-3). This method was chosen because published production values use a variety of different methods for estimating production and were performed in different years. The annual production of a cell will be calculated based the relationship of production and inundation (see algorithm section below) and the maximum production for the initial mapping unit habitat.

Table C.9-3   Production Values Compiled from the Literature for Each Habitat Type

Habitat	Turn Over Rate[+] (crops/ year)	Above-ground biomass (g/m²)	Root:Shoot ratio	Total Production* (g/m²/yr)
Bottomland Hardwood	NA	16,100[5]	NA	1,374[5]
Swamp Forest	NA	37,500[5]	NA	400[9]-1,780[6]
Fresh Floating Marsh	1.21[4]	314-2260[1]	3.5[7]	1,479-10,645
Fresh Attached Marsh	9.10[2]	635[8]	2.6[8]	7,430
Intermediate Marsh	4.16[2]	291-1499[1]	0.7[7]	1,414-7,285
Brackish Marsh	4.16[2]	441-1781[1]	0.7[7]	2,143-8,656
Saline Wetlands	2.91[2]	447-1750[1]	0.7[7]	1,614-6,318

[+]*Panicum hemitomon was used as the dominant for fresh floating marsh, Sagittaria lancifolia was used as the dominant for fresh attached marsh, Spartina patens was used for the dominant in intermediate and brackish marshes, Spartina alterniflora was used as the dominant for saline marshes*

*Total production for herbaceous marshes is calculated as follows:

Total production = (Aboveground biomass*turnover rate)+(Aboveground biomass*root:shoot ratio)
This assumes that turnover of root crop is 1 time per year

[1]*LOOP monitoring data 1979-97 yearly estimates of end-of-season biomass (g/m²)*
[2]*Hopkinson et.al. (1980)*
[4]*Sasser and Gosselink (1984)*
[5]*Conner and Day (1976)*
[6]*Conner et.al. (1981)*
[7]*Gosselink and Sasser (1995)*
[8]*Sasser et.al. (1994)*
[9]*Höppner (2002)*

9.3   SPATIAL AND TEMPORAL SCALES

The objective of this effort is to provide a conceptual model that can be used to predict restoration effects 50 years into the future for the entire Louisiana coast. Changes in vegetation composition can occur from year to year in marsh habitats (*e.g.* Visser *et.al.* 2002), whereas changes in species composition that occur in forested wetlands are much slower (Conner and Brody 1989). Thus, the habitat switching module uses an annual timestep as the smallest, common denominator, while using a 5-year interval for the evaluation of state changes affecting forested wetlands.

Large interannual and intra-annual variation in primary production occurs (*e.g.* Sasser *et.al.* 1995). To address the intra-annual variation in primary production, production will be estimated separately in each of three seasons as a percent of the total production: spring (March 1 – June 30), summer (July 1 – October 31) and fall/winter (November 1 – February 28). The percent contribution of each of these seasons to annual production was estimated from literature values for each of the habitat types (Table C.9-4).

Table C.9-4   Percent of Annual Primary Productivity by Season and Habitat Type

Season	Bottomland Hardwood[1]	Swamp[1]	Fresh[2]	Intermediate[3]	Brackish[3]	Saline[3]
MAR 1 – JUN 30	75%	75%	38%	40%	35%	29%
JUL 1 – OCT 31	25%	25%	48%	39%	35%	47%
NOV 1 – FEB 28	0%	0%	14%	21%	30%	24%
[1] *From Keeland and Sharitz 1995* [2] *From Sasser and Gosselink 1984* [3] *From Hopkinson et.al. 1978*						

Although the causes of habitat change operate at many spatial scales (*e.g.* global, basin, local; Gosselink and Sasser 1995), the importance of understanding local processes as the key to the restoration of coastal marshes is acknowledged. Ecosystem simulation models have used a spatial scale of .3 mi^2 (1 km^2) (*e.g.* Reyes *et.al.* 2000; Martin *et.al.* 2002). The habitat switching module was applied at the scale of 1 km^2.

9.4   DESKTOP ALGORITHMS

9.4.1   Habitat Switching Component

The habitat switching algorithms are illustrated below as matrices.

1 Year Time Step
Switch determined based on average annual salinity

Time 0 habitat	Time 1 habitat						
	UPL	**SWF**	**FAM**	**INM**	**BRM**	**SAW**	**WAT**
UPL	always	X	X	X	X	X	X
SWF	X	always	X	X	X	X	X
FAM	X	X	<2.5	2.5-9	X	X	>9
INM	X	X	<1	1-6	6-15	X	>15

BRM	X	X	X	<6	6-15	>15	X
SAW	X	X	X	X	=15	>15	X
WAT	X	X	X	X	X	X	X

10 Year Time Step
Switch determined based on average annual salinity over 10 years

Time 0 habitat	Time 10 habitat						
	UPL	SWF	FAM	INM	BRM	SAW	WAT
SWF	X	=4	X	>4	X	X	X

9.4.2 Habitat Productivity Component

The habitat productivity algorithms are illustrated below as matrices.

Bottomland Hardwood Production (Percentage of Maximum)						
Average Annual Salinity (ppt)						
Inundation	0	2	4	6	10	>10
0	70	42	28	14	0	0
10	80	48	32	16	0	0
20	100	60	40	20	0	0
30	85	51	34	17	0	0
40	75	45	30	15	0	0
50	65	39	26	13	0	0
60	58	34.8	23.2	11.6	0	0
70	51	30.6	20.4	10.2	0	0
80	44	26.4	17.6	8.8	0	0
90	37	22.2	14.8	7.4	0	0
100	30	18	12	6	0	0

Swamp Production (Percentage of Maximum)						
Average Annual Salinity (ppt)						
Inundation	0	2	4	6	10	>10
0	100	70	40	10	0	0
10	100	70	40	10	0	0
20	100	70	40	10	0	0
30	100	70	40	10	0	0
40	100	70	40	10	0	0
50	100	70	40	10	0	0
60	87.5	61.25	35	8.75	0	0
70	75	52.5	30	7.5	0	0
80	65	45.5	26	6.5	0	0
90	57.5	40.25	23	5.75	0	0
100	50	35	20	5	0	0

Fresh Marsh Production
(Percentage of Maximum)

Inundation	Salinity (ppt)								
	0	1	2	3	4	5	6	7	8
0	70	57.4	50.4	43.4	36.4	29.4	22.4	15.4	8.4
10	80	65.6	57.6	49.6	41.6	33.6	25.6	17.6	9.6
20	90	73.8	64.8	55.8	46.8	37.8	28.8	19.8	10.8
30	95	77.9	68.4	58.9	49.4	39.9	30.4	20.9	11.4
40	100	82.0	72.0	62.0	52.0	42.0	32.0	22.0	12.0
50	100	82.0	72.0	62.0	52.0	42.0	32.0	22.0	12.0
60	100	82.0	72.0	62.0	52.0	42.0	32.0	22.0	12.0
70	95	77.9	68.4	58.9	49.4	39.9	30.4	20.9	11.4
80	90	73.8	64.8	55.8	46.8	37.8	28.8	19.8	10.8
90	80	65.6	57.6	49.6	41.6	33.6	25.6	17.6	9.6
100	70	57.4	50.4	43.4	36.4	29.4	22.4	15.4	8.4

Intermediate Marsh Production
(Percentage of Maximum)

Inundation	Salinity (ppt)								
	0	2	4	6	8	10	12	14	16
0	70	70	57.2	50.4	43.8	37.0	30.2	25.6	24.4
10	80	80	65.4	57.6	50.0	42.2	34.5	29.3	27.9
20	90	90	73.5	64.8	56.3	47.5	38.8	32.9	31.4
30	95	95	77.6	68.4	59.4	50.2	40.9	34.8	33.2
40	100	100	81.7	72.0	62.5	52.8	43.1	36.6	34.9
50	100	100	81.7	72.0	62.5	52.8	43.1	36.6	34.9
60	100	100	81.7	72.0	62.5	52.8	43.1	36.6	34.9
70	95	95	77.6	68.4	59.4	50.2	40.9	34.8	33.2
80	90	90	73.5	64.8	56.3	47.5	38.8	32.9	31.4
90	80	80	65.4	57.6	50.0	42.2	34.5	29.3	27.9
100	70	70	57.2	50.4	43.8	37.0	30.2	25.6	24.4

Brackish Marsh Production
(Percentage of Maximum)

Inundation	Salinity (ppt)								
	0	2.5	5	7.5	10	12.5	15	17.5	20
0	40	40	40	40	34.1	32.4	30.8	29.2	27.6
10	60	60	60	60	51.1	48.7	46.3	43.9	41.5
20	100	100	100	100	85.2	81.1	77.1	73.1	69.1
30	100	100	100	100	85.2	81.1	77.1	73.1	69.1
40	100	100	100	100	85.2	81.1	77.1	73.1	69.1
50	100	100	100	100	85.2	81.1	77.1	73.1	69.1
60	85	85	85	85	72.4	68.9	65.5	62.1	58.7
70	40	40	40	40	34.1	32.4	30.8	29.2	27.6
80	10	10	10	10	8.5	8.1	7.7	7.3	6.9
90	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0

| Saline Marsh Production (Percentage of Maximum) | | | | | | | | | |
| Salinity (ppt) | | | | | | | | | |
Inundation	0	5	10	15	20	25	30	35	40
0	40	40	40	34.9	31.2	27.5	23.9	20.1	16.5
10	60	60	60	52.4	46.9	41.3	35.8	30.2	24.7
20	80	80	80	69.8	62.5	55.0	47.8	40.2	33.0
30	90	90	90	78.6	70.3	61.9	53.7	45.3	37.1
40	95	95	95	82.9	74.2	65.4	56.7	47.8	39.1
50	100	100	100	87.3	78.1	68.8	59.7	50.3	41.2
60	95	95	95	82.9	74.2	65.4	56.7	47.8	39.1
70	85	85	85	74.2	66.4	58.5	50.7	42.8	35.0
80	72	72	72	62.9	56.2	49.5	43.0	36.2	29.7
90	60	60	60	52.4	46.9	41.3	35.8	30.2	24.7
100	30	30	30	26.2	23.4	20.6	17.9	15.1	12.4

9.5   RESULTS

The habitat switching algorithm was used to predict the distribution of habitats at year 50 under all different subprovince frameworks. Subprovince 1 is being used as an example to illustrate these results, but results from the other subprovinces are comparable. The results from the switching algorithm are dependent on the salinity distribution (Figure C.9-5). Figure C.9-6 shows the spatial distribution of habitats predicted with the habitat switching algorithm under framework M02 and illustrates how land building in American/California Bay interacts with salinity changes.

Increases in land resulting from the different frameworks are primarily reflected by the increase in fresh attached marshes, while brackish marshes and saline wetlands decrease as sediment load diverted increases (Figure C.9-7). In addition, Figure C.9-7 illustrates the tradeoff between creating land and maintaining a large estuarine gradient.

Productivity index results show a similar distribution to the total wetland area created under each restoration scenario (Figure C.9-8).
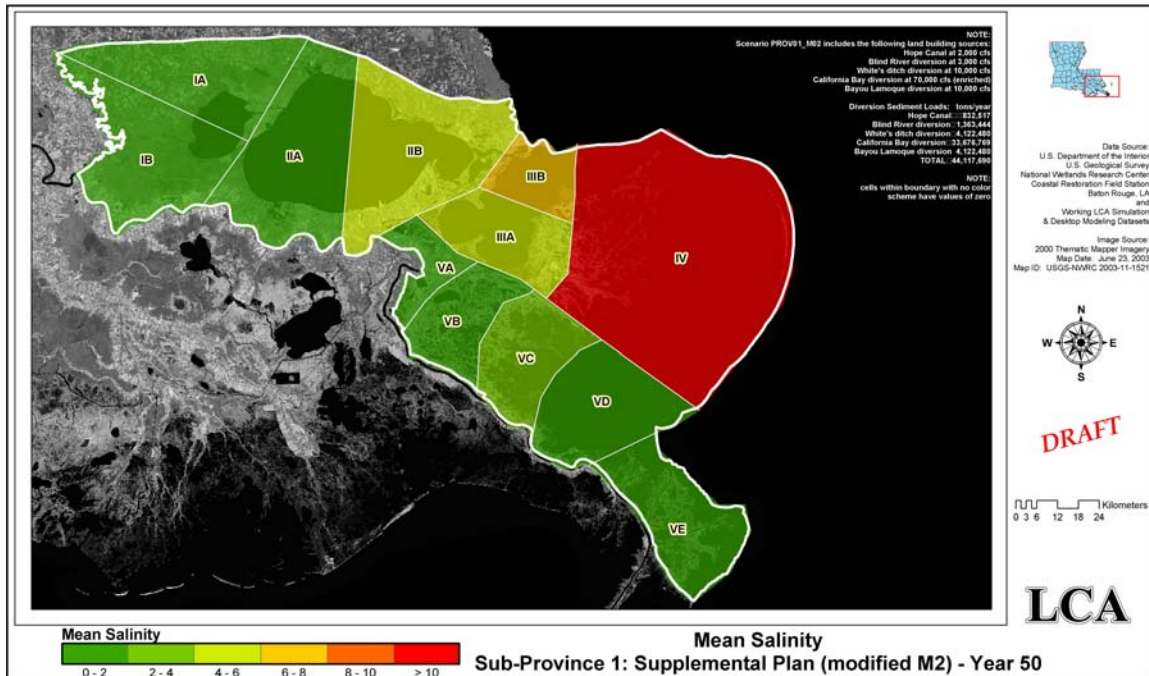
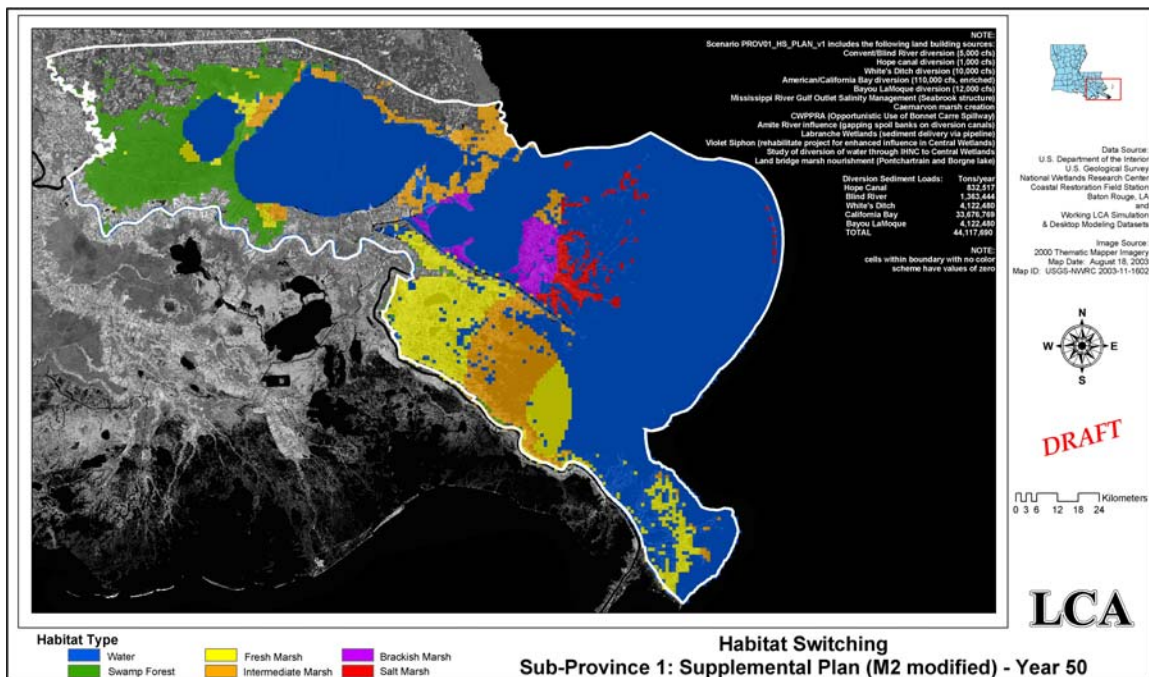**Figure C.9-5 Spatial Distribution of Average Annual Salinity in Subprovince 1 Under Restoration Framework M02**

Figure C.9-6 Spatial Distribution of Habitats in Subprovince 1 Under Restoration Framework M02
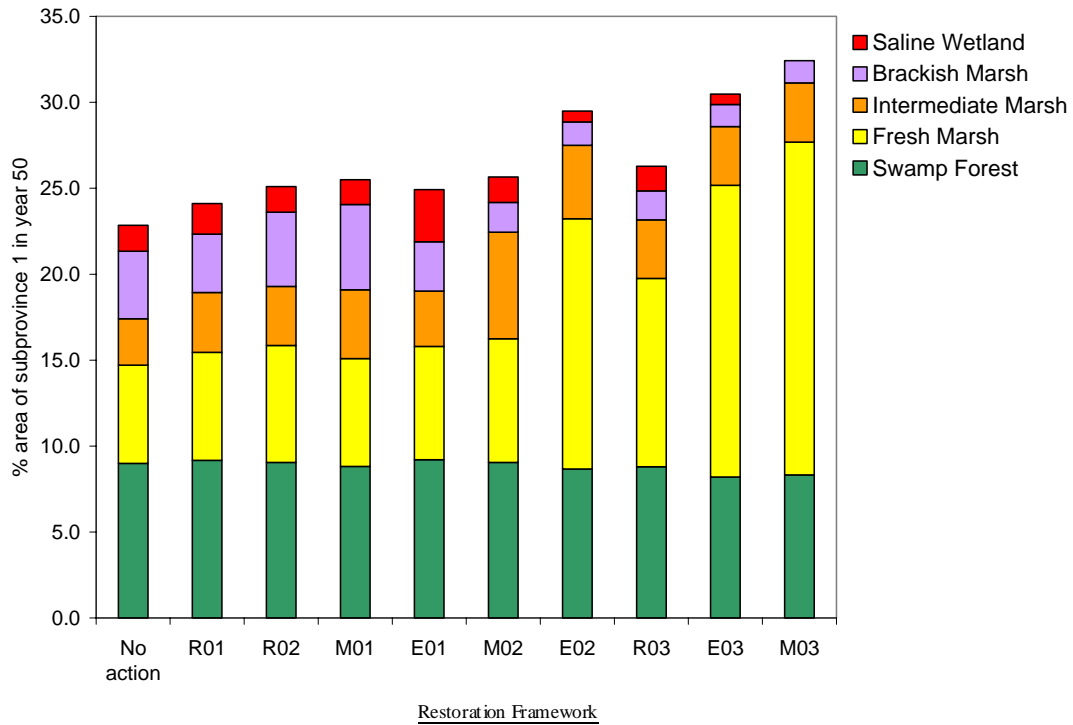
Figure C.9-7   Change in habitat composition resulting from different restoration frameworks. Order represents increasing sediment loads from diversions.
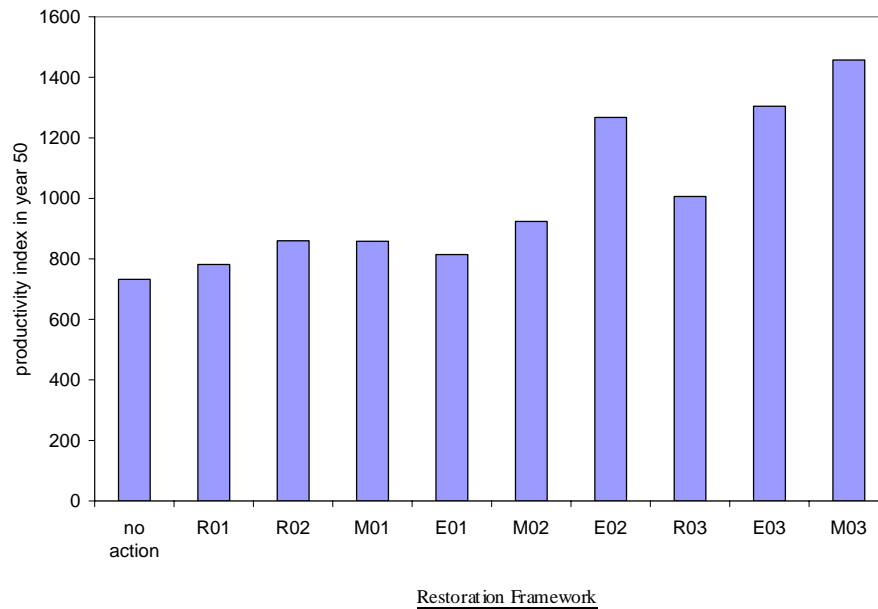

Figure C.9-8   Changes in marsh productivity index resulting from different frameworks. Order represents increasing sediment loads from diversions.